

Epidemiology of Meniscal Allograft Transplantation at Children's Hospitals in the United States

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Background: Meniscal allograft transplantation (MAT) was developed with the goal of delaying the progression of degenerative disease in the setting of substantial meniscal deficiency. This may be especially important in children and adolescents; however, there is a paucity of literature on MAT in this population.

Purpose: To evaluate the epidemiology of MAT at pediatric hospitals in the United States, with specific attention to regional and characteristic trends.

Study Design: Case-control study; Level of evidence, 3.

Methods: The Pediatric Health Information System, a national database consisting of 49 children's hospitals, was queried for all patients younger than 25 years who underwent MAT between 2011 and 2018. Characteristic information and surgical history were collected for each patient. The database was also queried for all patients who underwent other meniscal surgeries (including debridement, meniscectomy, and meniscal repair) during the same period (controls). Characteristic and geographic data from the control group were compared with those of the patients who underwent MAT. Univariate analysis was followed by purposeful entry multivariate regression to adjust for confounding factors.

Results: A total of 27,168 meniscal surgeries were performed in 47 hospitals, with MAT performed 67 times in 17 hospitals. Twelve (18%) patients underwent a subsequent procedure after transplantation. In multivariate analysis, each year of increasing age resulted in 1.1 times higher odds of having undergone MAT (95% CI, 1.03-1.1; $P = .002$) compared with repair or meniscectomy. Patients who underwent MAT also had 2.0 times higher odds of being women (95% CI, 1.2-3.3; $P = .01$) and 2.0 times higher odds of being privately insured (95% CI, 1.1-3.6; $P = .02$). MAT was performed most frequently in the Northeast (4.9/1000 meniscal surgeries) and least often in the South (1.1/1000 meniscal surgeries) ($P < .001$).

Conclusion: In the United States, pediatric and adolescent patients who underwent MAT were older and more likely to be female and have private insurance than those undergoing meniscal repair or meniscectomy. MAT was only performed in 17 of 47 children's hospitals that perform meniscal surgery. These trends highlight the need for further research, especially regarding differences along the lines of sex and insurance status.

Keywords: meniscal allograft transplantation; pediatric; knee; meniscus; sports medicine

The meniscus is a fibrocartilaginous structure that has essential functions at the knee including load transmission, joint lubrication, shock absorption, and stabilization.^{1,12,25} Numerous studies^{3,7,14,21,22} have demonstrated that changes to or loss of meniscal tissue increase the rate of degenerative changes, ultimately leading to early-onset osteoarthritis. At least 1 biomechanical study demonstrates that the loss of 20% of the meniscus results in a 350% increase in contact stress through the articular cartilage.¹⁸ The association between meniscal loss and osteoarthritis has resulted in a

shift of the treatment paradigm from excision to preservation, when possible.^{5,16,25}

There has been a recent rise in the incidence of pediatric meniscal injuries attributed to the increase in high-level competitive athletics, early sport specialization, and injury awareness.^{11,12} Meniscal injury and the resulting premature degenerative changes are especially concerning in children and adolescents, whose knees often face greater demand than those of adults and require optimal function over a longer lifespan.^{1,15,25} In children, a greater portion of the meniscus is vascularized, which makes it more amenable to repair,^{1,11} but some patients have complex tears that are irreparable. In pediatric patients, significant meniscal loss typically occurs after irreparable bucket-handle tears, frequently associated with ligamentous injuries, or after a

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torn discoid meniscus.^{11,12,25} A cadaveric study demonstrated increased contact pressures of 80% to 90% in knees that had undergone meniscectomies, raising concern of early degenerative changes in these young patients.⁸

Meniscal allograft transplantation (MAT) is an option for relatively young, active patients with substantial meniscal deficiency. The first MAT was performed in 1984 by Milachowski and Wirth with the goal of halting or slowing the progression of compartmental degeneration in patients with a symptomatic knee after a subtotal or complete meniscectomy.^{4,25} There was a delayed adoption of the procedure in pediatrics due to unknown effects of the allograft on the physis and concerns regarding the longevity of the graft.^{2,9,15,25} Subsequent pediatric case studies have demonstrated consistent improvements in functional outcomes, activity levels, and pain scores after MAT in children and adolescents.¹⁵ Furthermore, MAT survival appears to be better in patients with minimal chondral damage, justifying early referral and treatment in young patients.²

Despite the growing body of evidence supporting MAT in adults, there is a paucity of literature specific to children and adolescents. The purpose of this study was to evaluate the epidemiology of pediatric MAT in a large, nationally representative population within the United States, with attention to geographic and characteristic trends. Understanding such trends may provide a basis for further research, identify disparities in care, and improve patient counseling. Our hypothesis was that MAT would be a relatively uncommon procedure with variable usage along geographic and characteristic lines.

METHODS

This study utilized the Pediatric Health Information System (PHIS) database. PHIS is an administrative and billing database that contains inpatient, emergency department, ambulatory surgery, and observation data from not-for-profit, tertiary-care pediatric hospitals in the United States. The 49 hospitals that contribute data to PHIS are affiliated with the Children's Hospital Association (Lenexa, Kansas, USA), a business alliance of children's hospitals. Data are deidentified and subjected to a number of reliability and validity checks before being included in the database. Because all data were obtained from a deidentified administrative database, this study was exempt from institutional review board approval.

The PHIS database was queried for all patients younger than 25 years of age who underwent meniscal surgery

between 2011 and 2018 using Current Procedural Terminology (CPT), Fourth Edition, codes 29880, 29881, 29882, and 29883. The subset of patients who had undergone MAT were identified using the CPT code 29868. Normalization of the MAT data was performed using a control group of pediatric and adolescent patients who underwent meniscal surgeries (including repair, partial meniscectomy, and debridement) as a denominator to account for potential changes in utilization of PHIS; orthopaedic procedures at participating hospitals; and in the incidence, diagnosis, and treatment of meniscal injuries in the pediatric population. Furthermore, using these patients as a control population mitigated the effect on our data of hospitals that did not have pediatric sports surgeons.

Information of interest included characteristic data, geographic region (as defined by the US Census Bureau), and city pediatric population. Population data were also based on the US Census information and included the greater metropolitan area rather than only the city itself. Patients who underwent MAT were compared with patients who had minor meniscal surgeries (ie, repair or meniscectomy), with the goal of identifying characteristic or geographic differences between these cohorts. The records of patients who underwent MAT were further queried to identify patients who underwent a concomitant or subsequent surgical procedure.

Statistical analyses were performed with SPSS for Macintosh (Version 24.0; IBM). Calculations included standard descriptive statistics for characteristic variables, with means reported with standard deviations and medians reported with ranges. The Kolmogorov-Smirnov test was used to evaluate the normality of continuous variables. Means were compared with independent-samples *t* tests, and the Mann-Whitney *U* test was used for nonparametric variables. Analysis of categorical variables was performed using the Fisher exact and chi-square tests, as appropriate. Univariate analysis was followed by purposeful entry logistic regression to adjust for confounders. A significance threshold of $P < .05$ was used for all tests.

RESULTS

A total of 27,168 meniscal surgeries were performed in 47 hospitals, with MAT performed 67 times in 17 hospitals. Of the 27,101 minor meniscal operations, 55.5% were medial or lateral meniscectomy or debridement, 34.7% were medial or lateral repair, 5.2% were medial and lateral meniscectomy, and 4.6% were medial and lateral repair. Compared with patients who underwent meniscal repair

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Ethical approval was not sought for the present study.

TABLE 1
Comparison of MAT With Repair/Meniscectomy^a

	MAT (n = 67)	Repair/Meniscectomy (n = 27,101)	P
Age, y	16.6 ± 2.6	15.4 ± 3.3	.001
Sex			.006
Female	40 (59.7)	11,635 (42.9)	
Male	27 (40.3)	15,466 (57.1)	
Insurance			.004
Private	44 (65.7)	13,558 (50.0)	
Public	17 (25.4)	12,185 (45.0)	
Other/unknown ^b	6 (9.0)	1,358 (5.0)	
Race			.8
White	37 (55.2)	12,803 (47.2)	
Latinx/Hispanic	12 (17.9)	5,207 (19.2)	
Black	8 (11.9)	4,229 (15.6)	
Asian	1 (1.5)	500 (1.8)	
Other/unknown ^c	9 (13.4)	4,362 (16.1)	
Region			<.001
Northeast	31 (46.3)	6,356 (23.5)	
West	13 (19.4)	6,680 (24.6)	
Midwest	13 (19.4)	5,091 (18.8)	
South	10 (14.9)	8,974 (33.1)	
City pediatric population	983,268 (157,253-3,138,870)	662,290 (4,420-4,311,500)	.04

^aData are expressed as mean ± SD or n (%) except for city pediatric population, which is expressed as median (range). Bolded P values indicate statistically significant difference between groups. MAT, meniscal allograft transplantation.

^bOther insurances included self-pay, Tricare, or none.

^cOther races included Native American, Pacific Islander, or “Other” as directly indicated in the database.

TABLE 2
Additional Details of the MAT Cohort (N = 67)

Variable	n (%)
Laterality	
Right	33 (49.3)
Left	28 (41.8)
Unknown	6 (9.0)
Primary diagnosis	
Lateral meniscal tear	24 (35.8)
History of ACL injury	16 (23.9)
Medial meniscal tear	13 (19.4)
Discoid meniscus	4 (6.0)
Other ^a	10 (14.9)
Concomitant procedures	
ACL reconstruction	11 (16.4)
Osteochondral grafting or ACI	6 (9.0)
Guided growth procedure	3 (4.5)
Other	5 (7.5)
Subsequent procedures (n = 12)	
Meniscectomy	7 (58.3)
Chondroplasty	3 (25.0)
Implant removal	2 (16.7)

^aOther diagnoses included deformities about the knee, meniscal derangements “not elsewhere classified,” knee pain, and osteochondritis dissecans. ACI, autologous chondrocyte implantation; ACL, anterior cruciate ligament; MAT, meniscal allograft transplant.

or meniscectomy, the MAT cohort was older and had a higher proportion of women and privately insured patients (Table 1). Additional details of the MAT cohort are provided

TABLE 3
Patient Characteristic Predictors in Multivariate Analysis

	Odds Ratio (95% CI)	P
Age	1.1 (1.03-1.1)	.002
Sex: female	2.0 (1.2-3.3)	.01
Insurance: private	2.0 (1.1-3.6)	.02

in Table 2. Of note, 12 (18%) patients underwent a subsequent procedure at a median of 224 days after transplantation (range, 47-949 days).

When adjusting for covariates in multivariate analysis, each year of increasing age resulted in higher odds that MAT was performed rather than a minor meniscal procedure. Patients who underwent MAT were twice as likely be female and privately insured than those who had meniscectomy or repair. The details of this multivariate model are shown in Table 3.

Regional differences were observed. MAT was performed most frequently in the Northeast (4.9/1000 meniscal surgeries) and least often in the South (1.1/1000 meniscal surgeries) ($P < .001$). Furthermore, MAT was more likely to be performed in larger cities. The median pediatric population of cities in which MAT was performed was 983,268 (range, 157,253-3,138,870) compared with 662,290 (range 4,420-4,311,500) in cities where MAT was not performed ($P = .04$). These results maintained statistical significance in multivariate analysis (Table 4).

TABLE 4
Geographic Predictors in Multivariate Analysis^a

	Odds Ratio (95% CI)	P
City pediatric population	1.1 (1.1-1.2)	.04
Region (Northeast)		
South	0.3 (0.1-0.6)	.001
West	0.4 (0.2-0.8)	.005
Midwest	0.6 (0.3-1.2)	.2

^aBolded P values indicate statistical significance.

DISCUSSION

In this study of a large, nationally representative pediatric population, MAT was performed in a minority of children's hospitals in the United States. When compared with children and adolescents who underwent meniscal repair or meniscectomy, those who received a transplant were more likely to be older (1.1 times higher odds per increasing year), female (2.0 times higher odds), and privately insured (2.0 times higher odds). Additionally, MAT was performed more frequently in larger cities (1.1 times higher odds) and the Northeast (1.7-3.3 times higher odds than other regions). Understanding the epidemiology of this procedure in the pediatric population can guide future research, help identify disparities in care, and eventually improve patient outcomes.

Previous studies on pediatric MAT have demonstrated promising results, but these are limited to small series. Riboh et al^{19,20} found that functional outcomes were consistently improved in 32 patients throughout a 2-year follow-up period. Similar to our data, they found high rates of concomitant procedures at 47%. The overall reoperation rate was 22% with a meniscal reoperation rate of 6%.²⁰ A recent study⁵ of MAT in an athletic adult population (average age, 28 years) demonstrated a 77% rate of patient satisfaction and 76% rate of return to sport at an average of 1 year postoperatively. This study also demonstrated a reoperation rate of 28%. While these pediatric case series and more robust adult studies are promising, further research with larger study populations is needed to better understand MAT in children and adolescents.

MAT remains a relatively uncommon procedure at pediatric hospitals, with only 67 cases identified in 17 centers from 2011 to 2018. Cvetanovich et al⁶ conducted an epidemiologic study of MAT using PearlDiver, a database of privately insured patients. While the majority of patients in the study were adults, the subset of their data specific to patients younger than 25 years also demonstrated limited usage, with 119 transplantations compared with 8,680 meniscal repairs and 25,998 meniscectomies.⁶ The reasons for limited MAT usage are likely multifactorial and may include the technically demanding nature of the procedure, variation in surgical indications, and relatively high cost. Still, despite the relative infrequency of this procedure in children and adolescents, we found geographic differences in the frequency of meniscal transplantation across the United States. The exact reasons for this are beyond the

scope of these data. It is unclear whether the relatively high rate of MAT in the Northeast or in large cities, for example, is due to broader surgical indications in the area, more available specialists with expertise in MAT in the region, or other issues related to graft availability or cost. More research is required to better understand the optimal surgical indications for, and outcomes of, MAT in the pediatric population as well as to ensure that all children that may benefit from this procedure have access to it.

Our study noted several additional trends when evaluating patient characteristics. Each year of increasing age resulted in 1.1 times higher odds of having undergone MAT (95% CI, 1.03-1.1; $P = .002$). This may represent the lag time between initial injury or meniscal surgery and the development of symptoms related to meniscal loss. However, the level of clinical significance related to the age difference cannot be fully determined from our data. Additionally, patients who underwent MAT were more likely to be female. Interestingly, our finding contradicts the database study of Cvetanovich et al,⁶ which found that MAT was more likely to be performed in males. However, the majority of patients in the latter study were over 25 years of age and all privately insured, implying a different patient population than in the PHIS database. Given that one of the more common contexts for MAT is irreparable or degenerative meniscal tears associated with ligamentous injury, our reported trend aligns with the thoroughly reported sex differences in anterior cruciate ligament (ACL) tears.²⁴ Mansori et al¹³ examined 362 ACL-injured patients to evaluate the effect of patient characteristics on associated meniscal tear patterns and found that women had a higher rate of bucket-handle, degenerative, and complex tears than men. The higher incidence of ACL tears with more severe meniscal pathology in women may have a role in our reported sex differences in MAT utilization. However, such an association is hypothetical at this time and more research is needed to understand potential sex differences in MAT.

The present study also found that patients undergoing MAT had twice the odds of being privately insured compared with those who had more minor meniscal surgeries. Numerous studies^{10,17,23} have demonstrated that children with government insurance have limited access to orthopaedic care. Williams et al²⁶ found that publicly insured adolescents with ACL tears were more likely to have associated severe meniscal and chondral injuries and were more likely to require meniscal debridement rather than repair when compared with patients with private insurance. Patients with more severe meniscal injuries and requiring meniscectomy are more likely to suffer from postmeniscectomy syndrome and therefore be candidates for MAT, especially in the presence of ligamentous instability. Further research is needed to evaluate the possibility that adolescents with public insurance may have barriers to receiving care for more severe meniscal and chondral injuries.

The limitations of this study include those inherent to an epidemiologic database review. Additionally, the data are limited to the pediatric hospitals participating in the PHIS network. While this includes 49 major children's hospitals around the country, primary or subsequent operations at

other institutions cannot be accounted for. Furthermore, PHIS is an administrative database and contains limited clinical information. Therefore, we were unable to collect information on tear pattern, chronicity, rationale for treatment, or detailed clinical outcomes. On account of the small number of MAT procedures performed at a limited number of centers during the study period, it is possible that a select few institutions may have skewed the geographic trends. While CPT coding for meniscal procedures is relatively straightforward, there remains the possibility that coding errors could have affected the findings of this study.

CONCLUSION

Despite the growing research demonstrating satisfactory outcomes of MAT in pediatric patients, it is a rarely performed procedure at tertiary pediatric centers. The epidemiologic data in this study reveal that patients undergoing MAT are older and more likely to be women and privately insured than those undergoing more common meniscal procedures. Furthermore, transplantation was more likely to be performed in larger cities and in specific geographic regions. Further research is needed to understand the reasons for these differences as well as potential barriers affecting access to MAT for children and adolescents with severe meniscal deficiency.

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